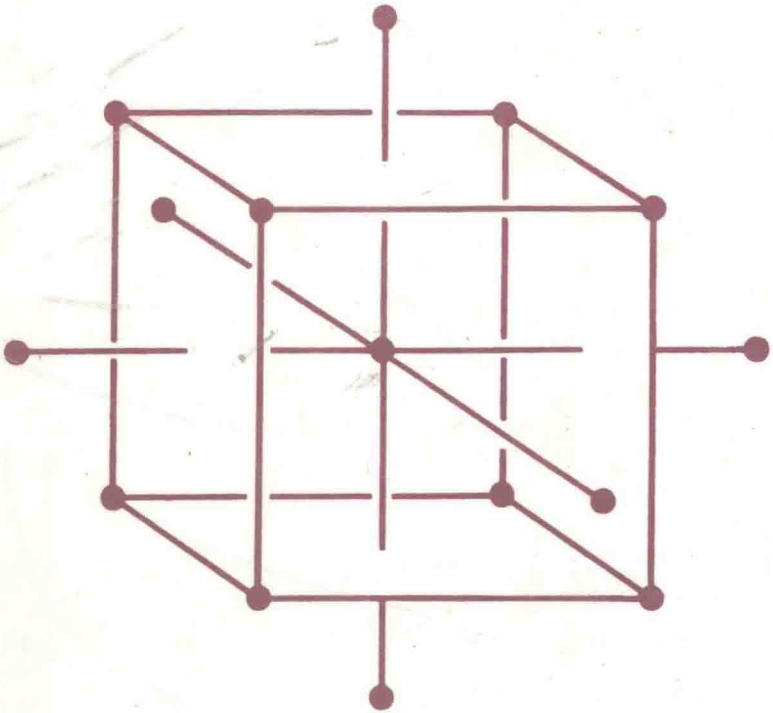
UNDERSTANDING INDUSTRIAL DESIGNED EXPERIMENTS

3RD EDITION



BLENDING *THE BEST OF THE BEST* DESIGNED EXPERIMENT TECHNIQUES

STEPHEN R. SCHMIDT
PhD, APPLIED STATISTICS

ROBERT G. LAUNSBY
MS, INDUSTRIAL ENGINEERING

UNDERSTANDING INDUSTRIAL DESIGNED EXPERIMENTS

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Stephen R. Schmidt

Robert G. Launsby

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The authors recognize that perfection is unattainable without continuous improvement. Therefore, we solicit comments as to how to improve this text. To relay your comments or to obtain further information, contact:

AIR ACADEMY PRESS
1155 Kelly Johnson Blvd. Suite 105
Colorado Springs, CO 80920
PHONE (719) 531-0777
FAX (719) 531-0778

ABOUT THE BOOK

The primary motivation for this book was to provide material that would bridge the gap produced by texts too mathematical and those that attain simplicity by omitting important concepts. This is an applications oriented text which blends the competing Taguchi, Shainin, and classical approaches to designed experiments. Included are over 200 pages of actual industrial case studies plus software.

ABOUT THE AUTHORS

Stephen R. Schmidt, Lt Col (Ret), served for twenty years in the U.S. Air Force both as an instructor pilot and as a Tenure Professor at the U. S. Air Force Academy. In addition to training over 4,000 engineers, managers, and college students, he has personally been a part of over 250 industrial experiments for a wide variety of Fortune 500 companies and their suppliers. Because of his vast experience, he now serves as president of Schmidt/Launsby Consulting and as an adjunct faculty member to the Six Sigma Institute, Motorola University. He earned a B.S. in Math at the U.S. Air Force Academy, an M.S. in Operations Research at the University of Texas and a Ph.D. in Applied Statistics at the University of Northern Colorado. Dr. Schmidt is also the co-author of two other recent texts: ***Basic Statistics: Tools for Continuous Improvement*** and ***Total Quality: A Textbook of Strategic Quality Leadership and Planning.***

Robert G. Launsby, M.S. in Engineering, is Executive Vice President of Schmidt/Launsby Consulting. He has over 20 years of industrial experience in management, engineering, training, and applications of problem solving approaches. Over the last 12 years he has led over 300 applications of statistical methods in a wide variety of industries. Possessing strong presentation and facilitation skills, he has instructed over two thousand persons in the use of statistical problem solving tools. Universities Bob has taught at include University of Colorado, University of Northern Colorado, University of Nebraska, University of Phoenix, Drexel University and Washington State University.

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Several short courses as well as on-site consulting are available. The focus of these activities is on empowering people with the techniques they need and can readily use. Available courses are:

- Basic Statistics (3 days)
- Advanced Topics in Design of Experiments (4 days)
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- Statistical Process Control (2 days)
- Total Quality Management (3 days)
- Management Overviews (2-4 hours)
- Quality Function Deployment (QFD) (3 days)

OTHER TEXTS BY AIR ACADEMY PRESS

Total Quality: A Textbook of Strategic Quality Leadership and Planning (1991) by K.D. Lam, F.D. Watson, and S.R. Schmidt. ISBN 0-9622176-9-7
This text is a comprehensive introduction to the philosophy, principles, tools and techniques of total quality. An excellent teaching tool for the university and community college level, it includes the basics of total quality as well as advanced topics such as QFD, experimental design, and total quality applied to software and education.

Basic Statistics: Tools for Continuous Improvement 2nd Edition (1991) by M.J. Kiemele and S.R. Schmidt. ISBN 0-9622176-8-9
The primary motivation for this book is to educate the readers (managers, engineers, researchers, analysts, practitioners, and statisticians) in the application of statistical tools to achieve continuous improvement in how they do business. It is designed for those taking a first course in statistics, as well as those who may have already taken a statistics course but need a refresher. The book uses applied examples to illustrate the use of statistical tools for continuous process improvement. It is easily read (calculus not needed) and there are no proofs. A statistical applications package, as well as other software, is included with the text.

Surviving the '90s and Winning! (1990) by B.D. Wellmon. ISBN 0-9622176-3-8
This book has been written specifically for everyone who has to work for a living–from the worker on the floor to the CEO or owner of the company. Whether your company has 91 people or 91,000; whether your business is manufacturing, service, or government; whether your customer base is local or global; this handbook should not only be read but used as a primer on your quest to survive the 1990's. This management survival handbook is designed as a practical reference guide and implementation tool for anyone in the business world. There are no theorems or claims of instant answers to all of your problems. There are no slogans or hidden secrets to be found. There are just three basic steps to be followed to guide you down the long and confusing path to improved quality. This book will help you master a system which is unique to your situation and which will contribute to your survival.

Total Quality Management: A Resource Guide (1990) by K.D. Lam.
This resource guide is designed to save you time and money. In it you will find hundreds of references to help you improve your TQM capabilities. In a handsome looseleaf binder, this well organized, comprehensive reference guide is designed for both TQM experts and novices. Those new to TQM will benefit from a chapter on "Getting Started," steps to take to start the TQM journey. It includes your role in the TQM process, your customers, key first steps, important tools and techniques you need to learn, and potential pitfalls to avoid.

Preface

The time is quickly approaching when you will not be considered a competent engineer or technical manager without a working knowledge of Experimental Design. The demands of increased efficiency of processes, lower product cost, and shortened development cycles will dictate that we use simple, but powerful tools to get the most out of our experiments. No longer do we have the luxury of running one-factor-at-a-time experiments or experiments with excessive sample sizes. In competitive environments, only those groups which **apply** experimental design approaches efficiently and effectively will survive.

Once engineers decide to start using orthogonal or nearly orthogonal designs, they are quickly faced with a plethora of competing design and analysis strategies. Full factorial, Plackett-Burman, Taguchi, and CCD are just some of the competing design types. What is the strength and weakness of each? What is the niche that each strategy best fills? How about analysis approaches? Should the engineer use "Pick the Winner", plots of marginal means, ANOVA, Normal Probability Plots, or Regression Analysis? In which situations do the competing analysis strategies best fit? Should the objective of the experiment influence the design type and analysis approach to be used? Is the objective of my experiment Screening, Modeling, or "Robust" Design? Is the Brainstorming session critical? Who should be involved?

Industry needs a handbook which answers the above questions! The following chapters offer what we believe are appropriate answers to the questions raised. Our approach is not to compulsively follow one specific philosophy of experimentation. Rather, the authors attempt to select the best from competing strategies, combining seemingly dichotomous techniques so as to produce a synergism which leads to an improved approach.

Acknowledgements

Writing a book is very similar to other major undertakings; it requires a team effort to produce a successful product. The magnitude of the team effort required becomes even greater when one considers the first edition of this product hit the market in early 1988. Now, only a couple of years later, the third edition has become a reality.

Many people have assisted in the continuous improvement of this text. A whole host of students from seminars and past university courses have been most helpful in providing suggestions. Several engineers have provided case studies or example problems. Still others have provided editorial support, suggestions, and encouragement. A special thanks must go to Debbie and Derek Brown for the original typesetting and editorial efforts on the first and second editions. Also, a special thanks goes to Diane Launsby for reformatting the entire text into its current form. Only she knows the incredible hours required to format, rework, and edit a text of this size. Thanks also to Ronda Churchill for editing and correcting the latest third edition manuscript. The following is a partial list of those who have helped make this text a success.

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Chapter 2 Conducting Simple Experimental Designs and Analysis

Chapter 3 Design Types

Chapter 4 Statistical Techniques

Chapter 5 Design Evaluation

Chapter 1

Foundations

1.1 Intended Audiences for this Text

This text was written for managers and engineers. It is intended to bridge the gap produced by texts that are too mathematical and those that attain simplicity by omitting important concepts. Mathematical and statistical theory are not emphasized; rather, the presentation is intended to provide conceptual understanding of designed experiments and related topics in statistical quality control. For years statisticians have provided us with textbooks written for understanding statistical theory, written primarily for those well versed in statistical jargon and mathematics. We recommend those texts for anyone seeking more depth into these subjects.

The presentation of material in this text is arranged to include a foundation for understanding experimental design (Chapter 1), an introduction to design and analysis (Chapter 2), a discussion of design types (Chapter 3), a review of basic statistical concepts and techniques (Chapter 4), an analysis of experimental data, variance reduction, and robust designs (Chapter 5), a presentation of Taguchi philosophy and analysis techniques (Chapter 6), an introduction to optimization and response surface methods (Chapter 7), and numerous case studies from industry (Chapter 8).

1.2 Quality and the Role of Statistical Techniques

The American Society for Quality Control has defined quality as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs." A simple interpretation of this definition is that quality is a measure of

how well the user's needs are met. The user's interpretation of quality focuses on whether the product functions as advertised with no variation in performance. There are several aspects of quality: the quality of the product design, the quality of the process design, the quality of incoming parts, and the quality of the manufactured product. In the design phase of the product or process, it is important to test which factors affect the quality of the design and determine the settings of these factors that optimize the desired output. In this phase, experimental designs and response surface techniques are used to develop a process which will produce a quality product. The quality of incoming parts and the quality of the manufacturing process are typically achieved through the use of statistical process control techniques; however, on-line experimental designs have also produced excellent results in these areas.

This text will focus on quality improvements through the applications of experimental design and present both sides to the controversy between Taguchi methods and classical techniques. The authors are not committed to either side, but advocate an approach which finds the "best" method for the practitioner to solve the problem at hand. Included are new ideas on how to combine certain aspects of both approaches in order to produce a synergism leading to improved methods of experimental design. Emphasis is on quality improvements and not on selling one approach or another. Also included are some important contributions from Shainin [11].

1.3 What is Experimental Design

Experimental design consists of purposeful changes of the inputs (factors) to a process in order to observe the corresponding changes in the outputs (responses). The process is defined as some combination of *machines, materials, methods, people, environment,* and *measurement* which when used together perform a service, produce a product, or complete a task. Thus, experimental design is a scientific approach which allows the researcher to better understand a process and to determine how the inputs affect the response.

Graphically, a process would appear as shown in Figure 1.1. Some examples of processes are shown in Figures 1.2 through 1.7. Obviously, there exist many different kinds

of processes; the ones provided are from various applications of designed experiments.

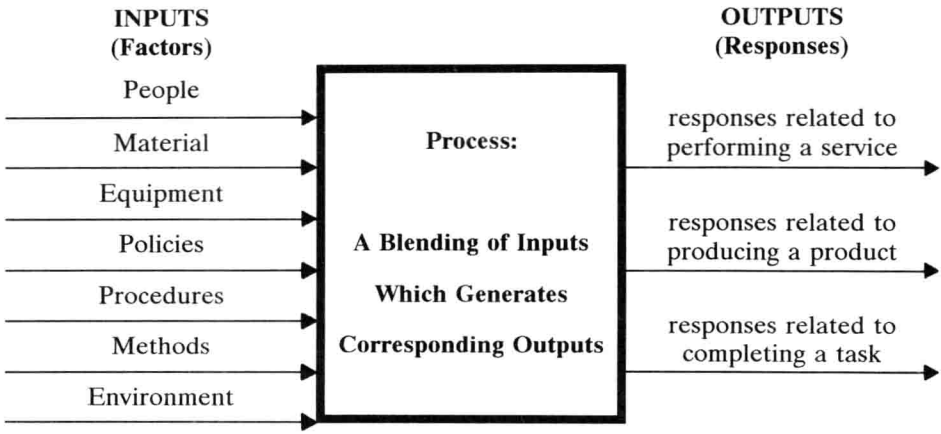

Figure 1.1 Illustration of a Process

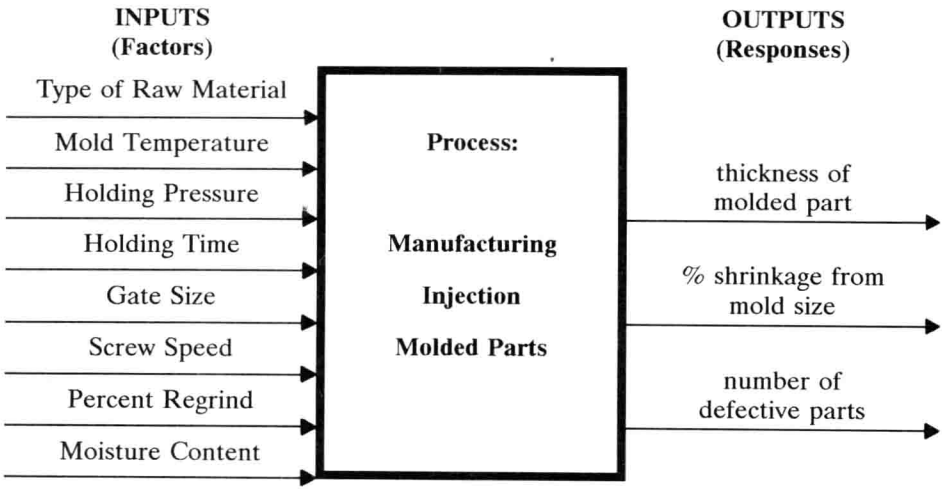

Figure 1.2 Manufacturing Injection Molded Parts

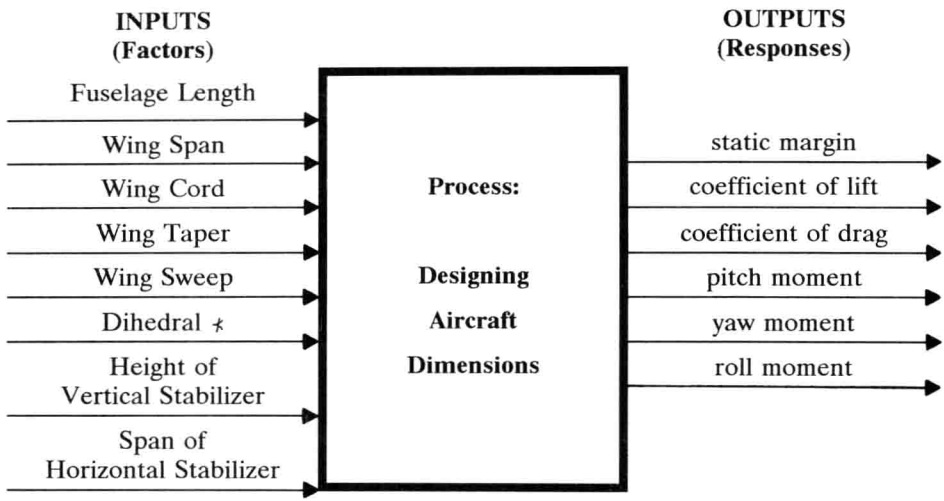

Figure 1.3 Aircraft Design

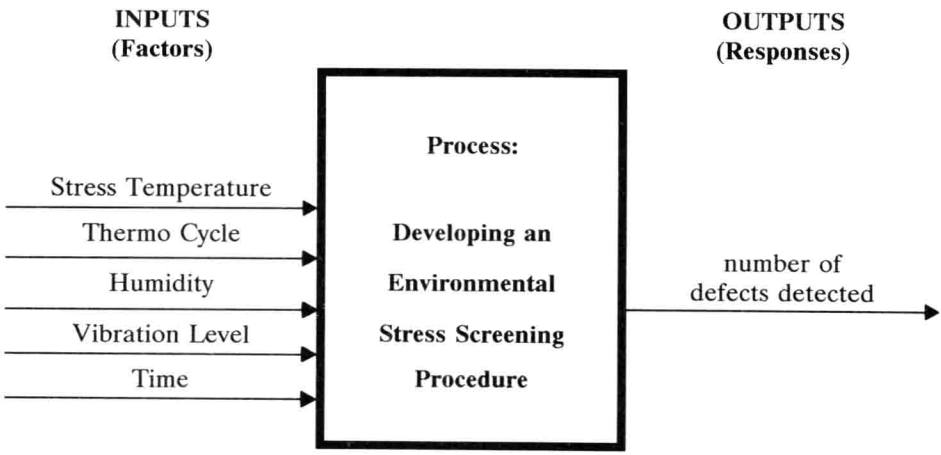

Figure 1.4 Developing an Environmental Stress Screen